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Design and Analysis of Bagasse Dryer to Recover Energy of Water Tube Boiler in a Sugar Factory

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Abstract: **The prices of sugar cane, sugar produced and molasses are fixed by the government authorities, hence the only method for generating profits for sugar mills is by reducing manufacturing cost where steam and fuel economy plays an important role. The aim of the present research work is to reduce the moisture content of the bagasse by designing the counter flow heat exchanger configuration to increase the dryness fraction of the bagasse. The proposed design of Bagasse Drier consists of a device wherein the hot flue gases are indirectly mixed with the wet bagasse falling on the conveyer plate from the crushing section. Є-NTU method is used for analysis of counter flow heat exchanger and 1-D conductive heat transfer is considered across a thin plate. Reduction of dryness fraction of bagasse has increased its GCV from 9471.378KJ/kg to 11818.122 KJ/kg which enhanced boiler efficiency by 63.288% to 72.877%. The wet bagasse dried up from 50.30% to 38.115%.**

*Keywords:***Bagasse;Є-NTU; Boiler Efficiency; Dryer; Moisture Contains;**

I. INTRODUCTION

India has been known as the first home of sugar and sugarcane. Indian mythology underpins the above truth as it contains legends demonstrating the base point of sugarcane. India is the second biggest maker of sugarcane after Brazil. Aside from sugar, the sugar business creates sure by-items, which can be utilized for generation of other modern items. The most critical by-item is molasses, which is used for generation of chemicals and liquor. Furthermore, the other critical by item is bagasse. It is primarily used as a hostage fuel in the boilers however it is additionally utilized as a crude material in the paper business. Sugarcane is a typical, perpetual grass that structures sidelong shoots at the base to deliver numerous stems, regularly three to four meters high and around five cm in measurement. The stems develop into stick stalk, which when develop constitutes around 75% of the whole plant.

A develop stalk is commonly made out of 11–16% fiber, 12–16% solvent sugars, 2–3% non-sugars, and 63–73% water. A sugarcane product is touchy to the atmosphere, soil sort, water system, manures, bugs, malady control, assortments, and the collect time frame. The normal yield of stick stalk is 60–70 tons for each hectare every year. In any case, this figure can change in the vicinity of 30 and 180 tons for every hectare relying upon information and yield administration approach utilized as a part of sugarcane development. Sugarcane is money edit; however it is likewise utilized as animals feed.

Bagasse is the stringy deposit staying when sugarcane are squashed to remove the juice. Customarily bagasse has been a waste by result of the sugarcane creation handle. All the more as of late is has been utilized as a fuel hotspot for sugar processes, a fiber for paper generation and as every year inexhaustible asset in the creation of reasonable materials and bundling.

When sugarcane is collected it is conveyed to a processing plant where it is squashed – regularly with a progression of expansive rollers. The rollers squash the sugarcane stalks and in this way extricate the juice from the sugarcane. The juice is gathered and expelled to be handled into sugar. The staying stringy stalk (which has been pounded, pressed, and expelled of its juice) is bagasse.

Ordinarily the misty bagasse comprises nearby 45per cent to 55 per cent moisture, which will have around 2270 Kcal/kg gross calorific value. The bagasse is directly fed to boiler as main fuel to produce steam and extra bagasse is put away in the bagasse yard. The boilers introduced in the plants are intended to consume bagasse with this moisture.

GCV of bagasse is to a great extent subordinate on its dampness percentage. Higher dampness content in the bagasse reduces its GCV, furthermore brings about higher vitality misfortune in light of the fact that the fuel dampness conveys that inert warmth of vaporization up the stack.

II. RESEARCH OBJECTIVES

- The aim of the proposed research work is to reduce the moisture content of the bagasse by designing a waste heat recovery system.

- GCV of bagasse is to a great extent subordinate upon its dampness content.
- Bagasse with high moisture strongly affects its GCV and hence diminishes the GCV. Bagasse with high moisture percentage will be the results of high energy loss. This is because the most of the heat will be lost to remove the moisture present in the bagasse which is directly fed to boiler as a main fuel.
- Proposed project work is to reduce the moisture content of the bagasse by designing a three-dimensional conjugate heat transfer system which will give maximum reduction in moisture content in bagasse by just using output of the boilers used in the sugar factory, i e. hot flue gases which will fed to atmosphere.

III. BAGASSE DRYING METHODS

INDIRECT DRYING METHOD

In an Indirect type dryer, a metal wall divide the product and the heat transfer medium.The heat transfer is only through conduction and forced convection.This method can be adopted for low pressure steam bagasse which ranges about 3 atm or less. It is made by inserting large tube bundles in a large bin. Typically, the bagasse moisture can be reduced from 50% to 35%.

DRYER DRYING METHOD

The work proposed, which will give maximum reduction in moisture content of bagasse by just using hot flue gases of the boiler output which will fed to atmosphere. The proposed research will have heat recovery system wherein the hot flue gases with temperature around 150° come in contact (Indirect) with bagasse and transfer the heat to wet bagasse with temperature 60° to 65° falling on the conveyer plate. The wet bagasse consists of around 45% to 55% moisture with a gross calorific value of around 2270 Kcal/kg (~9500 kJ/kg).

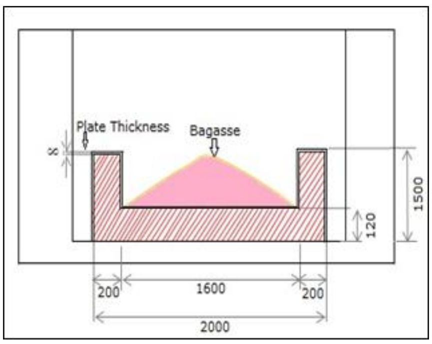


Fig Proposed design for bagasse drier.

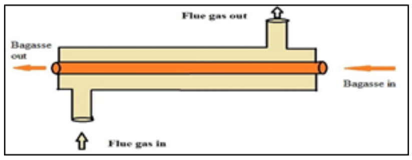


Fig.4.2 Counter Flow Heat Exchanger process flow.

The bagasse is directly fed to the boiler as a fuel to generate steam and excess bagasse is stored in the bagasse storage yard. The boilers installed in the plant are designed to burn bagasse with this moisture. It is a well-known fact that the CV of bagasse is mostly dependents on its moisture content. Higher moisture content in bagasse reduces its GCV and also results in higher energy loss because the fuel moisture carries that latent heat of vaporization up the stack.

Hence with the designed heat recovery system, the heat transfer will take place between hot flue gases and bagasse, thereby reduces the moisture content of bagasse.

Assessing in dryness portion of bagasse expands its CV which upgrades boilers productivity. Since 90% of misfortunes from the boilers are stack misfortunes and out of these misfortunes the dampness misfortune is the most noteworthy. In this way by diminishing the dampness substance of the bagasse, effectiveness of the heater can be enhanced and bagasse spared will be accessible for other utilize.

IV. HEAT EXCHANGERS

COUNTER FLOW HEAT EXCHANGE

In a counter flow heat exchanger the two fluids flow in opposite directions. The hot and cold fluids enter at the opposite ends. The flow arrangement and temperature distribution for such a heat exchanger are shown schematically in figure. The temperature difference between the two fluids remains more or less nearly constant. This type of heat exchanger due to counter flow,which gives maximum rate of heat transfer for given surface area.

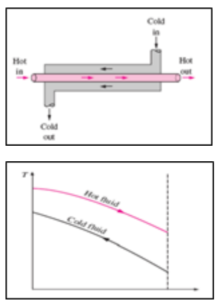


Fig.Counter flow heat exchanger

WAY OF ARRANGEMENT

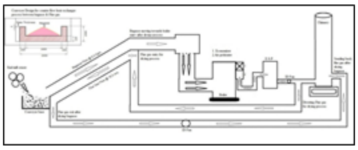


Fig. counter flow arrangement of bagasse and flue gas

The figure shows the way of arrangement of bagasse just after the final crusher to the boiler entrance as a fuel. Once the bagasse fall on the conveyer plate after the final crushing unit, the bagasse moves towards the boiler section with the slop of 34 m length as shown in the figure.

DUCT ARRANGEMENT FOR FLUE GAS FLOW

As the proposed project work is to minimize the moisture content of the bagasse using the high temperature flue gas which is emitted to atmosphere through the chimney. The flue gas has to be diverted from the chimney in order to dry the bagasse by encountering the counter flow heat exchanging process. The economical and easiest way to divert the flow of flue gas is at the bottom portion of chimney and just after the ID fan. By diverting the flue gas just after the ID fan will give us the better flow speed because of the ID fan which moves a quantity of air or gas by adding sufficient energy to the stream to initiate motion and overcome all resistance to flow. The flow speed of the flue gas is calculated from the ID fan speed which will be rotating at the speed of 980 rmp. Hence the flow speed of the flue gas is given by

The proposed work is to dry the bagasse just after falling down to the conveyor from the crusher. The bagasse will move in a slope of 2 m width plate after falling on the conveyor plate and then enters the boiler as a fuel as shown in the fig.

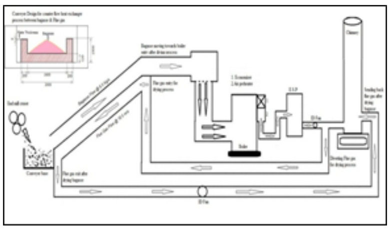


Fig. Proposed layout of bagasse drying process

FLUE GAS EXIT ARRANGEMENT AFTER DRYING PROCESS

Once the flue gas is diverted after the ID fan, the flue gas with temperature around 150^0 will flow through the 1.48 m diameter pipe and enters the rectangular duct of (1.5 m × 2 m) size. There in the conveyer section where heat exchanger takes place from flues gas to bagasse. After heat exchanger process the flue gas temperature slower down to around 74^0 will exits the conveyer section rectangular duct. The flue gas will be sent back to chimney with help of 1 m diameter pipe.

The sufficient care has to be taken in order to maintain the low temperature flue gas and the high temperature flowing in the chimney in order to send the flue gas which is brought from the heat exchanger section, it's very important to maintain the same velocity and pressure of the flue gas brought back to chimney from the heat exchanger section so as to smooth flow inside the chimney.

- The sufficient care has to be taken to push the flue gas with low temperature after drying process of bagasse with the help of ID fan.
- The diameter of the exit pipe after drying process is 1 m just to maintain the pressure with using any external aid to push the flue gas
- The exit flue gas velocity and pressure has to match with the flue gas moving inside the chimney which is achieved by decreeing or increasing the exit flue gas pipe.

DESIGN OF CONVEYOR FOR BAGASSE DRYING PROCESS

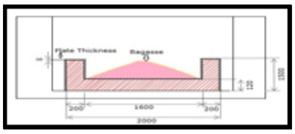


Fig. Proposed design for drying bagasse using flue gas

Fig. 6.8 actual conveyor

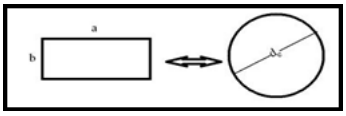
In order to fill the volume of the conveyer plate surrounding on which the bagasse will be moving towards boiler entrance, the diameter of the pipe on which flue gas will be brought to conveyer plate is found with the following equation.

$$d_e = 1.30 \times \frac{(a \times b)^{0.625}}{(a+b)^{0.25}}$$

Where

d_e=Equivalent diameter (mm)
a = Length of major or minor side (mm)
b = Length of minor or major side (mm)

The equivalent diameter is the diameter of a circular duct or pipe that gives the same pressure loss or resistance as an equivalent rectangular duct or pipe.



Hence the Diameter of the flue gas pipe is found to be

d_e=1.30(1600*120)$^{0.625}$/(1600+120)$^{0.25}$+1.30(1500*200)$^{0.625}$/1500+200)$^{0.25}$+1.30(1500*200)$^{0.625}$/1500+200)$^{0.25}$=1.30 (2004.76)/ (6.34) + 1.30(2649.72) / (6.42)+1.30(2649.72)/(6.42)=411.07+536.55+536.55=1484.17 mm

d_e=1.48 m

Radius of the pipe = 0.74 m

The Data Collected From Shri Halashidhanath Sahakari Sakkare Karkhana Niymit Nippani.

Mass flow rate of bagasse, m_b= 6.5kg/s
Specific heat at constant pressure of bagasse,

Cp_b = 1.018KJ/kg

Initial temperature of bagasse after end mill= 60^0C.

Specific Heat of flue gas, Cp_g =0.2808 kj/kg Initial temperature of flue gases after ID fan=135^0C

Velocity of flue gas = 10.5 m/s

Ambient temperature of air = 31 ^{0}C Characteristic length for inner flue gas flow is 0.37 m

Velocity of ambient air = 3.5 m/s

V. DESIGN ANALYSIS

COEFFICIENT OF CONVECTIVE HEAT TRANSFER FOR INTERNAL FLOW

$h_i = (N_u \times K) / L$

Where N_u = Nusselt number

K = Thermal Conductivity of Flue Gas

L = Characteristic length

Nusselt Number, $N_u = 0.02\ Re^{0.8}$

Where

Re=Reynolds Number for internal flow.

Reynolds Number for internal flow,

$R_e = (V \times L) / \upsilon$

Where,

V = Velocity of flue gas (m/s)

L = characteristic length (m)

υ = Kinematic Viscosity (m^2/s)

Characteristic length (m) = cross sectional area of pipe / perimeter of the tube= $(\pi \times (1.48/2)^2)/(2\times\pi\times(1.48/2))$

Characteristic length (m) =1.72/4.64=0.37 m

At a temperature of 98^o C the kinematic viscosity of air is approximated by:

$\upsilon = (0.1335 + 0.925 \times 10^{-3} \times t) \times 10^{-4}\ m^2/s$
$= (0.1335 + 0.925 \times 10^{-3} \times 135) \times 10^{-4}\ m^2/s$

Kinematic viscosity = 0.00002628 m^2/s

Reynolds Number for internal flow,

$R_e = (V \times L) / \upsilon$

= (10.5 x 0.37) / 0.00002628

Reynolds Number for internal flow,

Re = 147831.050

Hence the flow is Turbulent.

Nusselt Number, N_u = 0.02

Re $^{0.8}$= 0.02 x 147831.050$^{0.8}$

N_u= 273.427

N_u = h x L / k

Thermal Conductivity of Flue Gas @ 135 ^{o}C,

K = 0.02442 + 0.6992 x 10^{-4} x

T_{gi}=0.02442 + 0.6992 x 10^{-4} x 135

Thermal Conductivity of Flue Gas @ 135 ^{o}C,

K = 0.0338 W/mk

Coefficient of Convective Heat Transfer For Internal Flow

$h_i = (N_u \times K) / L$

= (273.427 x 0.0338) / 0.37

h_i= 24.977 W/m^2k

Coefficient of Convective Heat Transfer For External Flow

$h_o = N_u$ x K / L

Where N_u = Nusselt number

K = Thermal Conductivity of Flue Gas

L = Characteristic length

Nusselt Number, $N_u = 0.24\ Re^{0.6}$

Where Re = Reynolds Number for external flow.

Reynolds Number for internal flow,

$R_e = (V \times L) / \upsilon$

Where,

V = Velocity of flue gas (m/s)

L = characteristic length (m)

υ = Kinematic Viscosity (m^2/s)

t [° C]	ρ [kg/m³]	c_p [kJ/kgK]	μ *10⁶ [Pas]	ν *10⁶ [m²/s]
0	1.295	1.042	15.8	12.2
100	0.95	1.068	20.4	21.54
200	0.748	1.097	24.5	32.8
300	0.617	1.122	28.2	45.81
400	0.525	1.151	31.7	60.38
500	0.457	1.185	34.8	76.3
600	0.405	1.214	37.9	93.61
700	0.363	1.239	40.7	112.1
800	0.33	1.264	43.4	131.8
900	0.301	1.29	45.9	152.5
1000	0.275	1.306	48.4	174.3
1100	0.257	1.323	50.7	197.1
1200	0.24	1.34	53	221

Table 6.7 Kinematic viscosity with flue gas temperature

Characteristic length (m) = cross sectional area of pipe / perimeter of the tube
$= (\pi \times (1.48/2)^2)/(2\times \pi\times(1.48/2)$
$= 1.72/4.64 = 0.37$ m

At a temperature of 31° C the kinematic viscosity of air is approximated by:

$\upsilon = (0.1335 + 0.925 \times 10^{-3} \times t) \times 10^{-4}\ m^2/s$ $= (0.1335 + 0.925 \times 10^{-3} \times 31) \times 10^{-4}\ m^2/s$ $= 0.000016217\ m^2/s$

Reynolds Number for internal flow,
$R_e = (V\times L) / \upsilon$
$= (10.5 \times 0.37) / 0.000016$
$Re = 242812$

Hence the flow is Turbulent.

Nusselt Number, $N_u = 0.24\ Re^{0.6}$
$N_u = 408$

Thermal Conductivity of Flue Gas @ 31°,

$K = 0.02442 + 0.6992 \times 10^{-4} \times T_{gi}$
$= 0.02442 + 0.6992 \times 10^{-4} \times 31$
$= 0.02658$ W/mk

Hence, $h_o = (N_u \times K) / L$
$= (408 \times 0.02658) / 0.37$
$h_o = 29.30\ W/m^2k$

Internal coefficient of heat transfer (h_i)
$h_i = 24.977 W/m^2K$

External coefficient of heat transfer (h_o)
$h_o = 29.30\ W/m^2K$

Thermal conductivity of mild steel,
$K_{ms} = 45$ W/mK

OVERALL COEFFICIENT OF HEAT TRANSFER (U)

$U=1/[1/h_i + L/K + 1/h_o]$
L=0.008 m
$U=1 / [1/24.977+0.008/45+1/29.30]$
$U = 13.4589 W/m^2K$

Number of transfer unit (NTU)

$NTU = UA/C_{min}$
Where, A = Surface area of heat transfer
A = width × Height
$= 1600\times1380$
$= 2208000\ mm^2$
$A = 2.208\ m^2$

Heat Capacity (C)
Heat Capacity of bagasse (Cb)
$C_b = m_b \times C_{pb}$
$= 6.5 \times 1.055$

$C_b = 6.857$ KJ/Sec

Heat capacity of flue gas (C_g)
Here mass flow rate of flue gas (m_g)

$m_g = \varrho\ A\ V$ [cross ectional area of pipe $=(\pi \times (1.48/2)^2 = 1.72\ m^2$]
$= 1.125 \times 1.72 \times 10.5$
$= 20.32$ kg/s

$C_g = m_g \times cp$ $= 20.32 \times 0.2808$
$= 5.70$ KJ/Sec

Hence $C_b > C_g$
So, $C_{min} = C_g = 5.70$ KJ/Sec
Now,
$NTU = UA/C_{min}$

$= 13.458 \times 1.72 / 5.72$
$= 4.046$

Effectiveness of heat exchanger
$\varepsilon = [1-e^{(-NTU(1-R))} / (1-Re^{(-NTU(1-R))}]$ Where,

$R = \frac{C_{min}}{C_{max}} = \frac{5.70}{6.61} = 0.8644$

$\varepsilon = [1-e^{(-4.046(1-0.86)}] / [1-0.86e^{(-4.046)(1-0.86)}]$ $\varepsilon = 0.84$ Now,

Heat transfer in bagasse dryer
$Q = \varepsilon \times C_{min} \times (T_{gi}-T_{bi})$
$= 0.84 \times 5.70 \times (135-60)$
$= 359.1$ Kw

Final Temperature of bagasse
$Q = m_b \times C_{pb} \times (T_{bo}-T_{bi})$
$359.1 = 6.5 \times 1.055 \times (T_{bo}-60)$
$T_{bo} = 112.366^0C$

Final Temperature of flue gases
$Q = m_g \times C_{pg} \times (T_{gi}-T_{go})$
$359.1 = 20.32 \times 0.2808 \times (135-T_{go})$
$T_{go} = 72.064^0C$

Moisture reduction in bagasse
Enthalpy decrease in gas

$= m_g \times C_{pg} \times (T_{gi}-T_{go})$
$= 20.32\times0.2808\times(135-72.064)$
$= 359.1037$

Enthalpy increase in moisture
$= m_b \times C_{pb} \times (T_{bo}-T_{bi})$
$= 6.5\times1.055\times(112.366-60)$ $= 359.0998$

Enthalpy increase in moisture.
$= M_F h_2 + [M-M_F] \times (h_{go}-M_{h1})$
Where,
M = Initial moisture content in the bagasse at temperature Tbi

MF= Final moisture content in the bagasse at temperature Tbo

h_1 =Enthalpy of moisture at temperature $_{Tbo}$ $h_{2=}$ Enthalpy of moisture in bagasse at T_{bi} $h_{=}$ Enthalpy of gas at T_{gi}

From steam tables

h_1 = 469.8 KJ/kg
h_2 = 251.1 KJ/kg
h_{go} = 2726.6 KJ/kg

THE ENERGY BALANCE EQUATION FOR THE BAGASSE DRYER

m_g x C_{pg} x $[T_{gi}-T_{go}]$ = m_b x C_{pb} x $[T_{bo}-T_{bi}]$ + M_Fh_2+ $[M-M_F]$ x h_0-Mh_1

m_g x C_{pg} x $[T_{gi}-T_{go}]$ - m_b x C_{pb} x $[T_{bo}-T_{bi}]$ + M_Fh_2 + Mh_1 =Mh_o-M_Fh_o

m_g x C_{pg} x $[T_{gi}-T_{go}]$ - m_b x C_{pb} x $[T_{bo}-T_{bi}]$ + $M(h_1-h_o)$ = - M_F (h_o+h_2)

20.32 × 0.2808× (135-72.064) – 6.5×1.055 × (112.366-60) + 0.503 (469.8-2726.6) = -M_F (2726.6+251.1)

-1135.1704= -M_F (2978.2) M_F = -1135.1704 / -2978.2 M_F = 0.38115

FINAL MOISTURE OF BAGASSE (M_F)

M_F = 0.38115×100
M_F= 38.115%

FLUE GAS EXIT ARRANGEMENT AFTER DRYING PROCESS

Once the flue gas is diverted after the ID fan, the flue gas with temperature around135^0 will flow through the 1.48 m diameter pipe and enters the rectangular duct of (1.5 m × 2 m) size. There in the conveyer section where heat exchanger takes place from flues gas to bagasse. After heat exchanger process the flue gas temperature slower down to around 72.064℃ will exits the conveyer section rectangular duct. The flue gas will be sent back to chimney with help of 1 m diameter pipe.

VI. RESULT AND DISCUSSION

Fuel economy depends upon proper milling, efficient generation of steam and its use in the sugar factory. Fuel economy is directly related to moisture per cent bagasse. The design of heat exchanger as bagasse dryer seems effective to reduce the moisture per cent of the bagasse. The increase in boiler efficiency due to reduced moisture per cent of bagasse is analyzed. At the 50.30% of moisture the boiler efficiency was 63.288% and after drying the bagasse with the proposed drier system the moisture per cent reduced to 38.115% and the improved boiler efficiency is 72.877%. Thetemperature of bagasse after drying is increases and the moisture content in the bagasse is decreases. The calorific value of bagasse is also is increases with reduction in moisture.The final temperature of bagasse and flue gases from the bagasse dryer is given as follows

Total heat transfer in heat exchanger
Q = 359.1Kw

Final Temperature of bagasse after drying
T_{bo}=112.064^{0}C

Final Temperature of flue gases after drying
T_{go}=72.064^{0}C

Final moisture content in bagasse afterdrying
M_F =0.38115

% of moisture after drying is 38.115%

Efficiency of Boiler before Drying bagasse, η = 63.288%

Efficiency of Boiler after Drying bagasse, η = 72.877%

By adopting the improved milling such as adoption of proper mill settings , differential, grovings, hot water imblition, application of lotus roll, donally chutes and optimum hydraulic load with the proposed bagasse drying process it has been expected to achieve around 6% to 12% of moisture reduction and 10% increment in the boiler efficiency.

VII. CONCLUSION

The aim of project work proposed was to design a bagasse drying technique and to numerically analyze which it is achieved by **6.15%** by just utilizing the flue gas heat, the wet bagasse dried up from **50.30** to **38.115%.** Reduction in the moisture content of bagasse has increased its CV from **2261**Kcal/Kg to **2715**KCal/Kg which enhanced boiler efficiency by **63.2822%** to **72.877%** The main objective of the project is to design bagasse drying system to reduce the moisture percent in the bagasse, hence to improve boiler efficiency and to improve the manufacturing cost of per sugar bag device. The analytical results obtainable show evidently that the amount of moisture percentage can be reduced by using the hot flue gas and which will directly increases the efficiency of the boiler in the sugar.

VIII. FUTURE SCOPE

- ❖ The design analysis of bagasse drier report has been submitted to the Shri. Halasidhanath Sahakari Sakkare Karkhana Ltd. Nippani.

It has been suggested to sugar factory that the use of conveyor plate material of copper or aluminum then the M S steel will further improve the efficiency of the boiler.

- ❖ boiler by drying the bagasse. The next step would be to carry out the numerical analysis by considering the conveyor plate material as Copper and aluminum in order to increase the boiler efficiency by reducing the moisture content of bagasse.

- Once the analytical work finished and by taking in to account of Aluminum, copper and ms steel plate, the next step would be to carry out the CFD simulations.
- The analysis part of whole research work is planned to carry out with the help of Computational Fluid Dynamics simulation tools. Expected a minimum of 12% to 15% reduction in the moisture content in bagasse with the proposed computational work.
- After getting the 3D CFD simulation result, comparison will be carried out with analytical work and computational work, a proto type of the drying technique proposed in this project work will be created in Shri. Halasidhanath Sahakari Sakkare Karkhana Ltd. Nippani.to carry out the experimentation for the proposed work.
- After analyzing the numerical analysis, computational analysis and experimental work on the drying technique, implementation of the bagasse drier will be done in Shri. Halasidhanath Sahakari Sakkare Karkhana Ltd. Nippani.

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